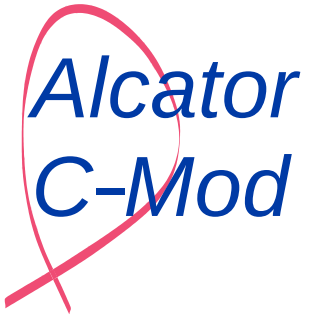
Alcator C-Mod Program



Program Science Objectives	Hutchinson	15m
Budget, Schedules, and Manpower	Marmar	20
MIT Institutional Issues	Porkolab	10

Program Exploits Unique Features of the C-Mod Tokamak

Alcator C-Mod

Major thrusts:

Quasi-steady Advanced Tokamak:

utilizing long pulse length cf L/R, new LH facility.

Burning Plasma Support:

High B; reactor pressure, $q_{||}$; i-e coupled; Mo PFCs.

Unique dimensional parameters

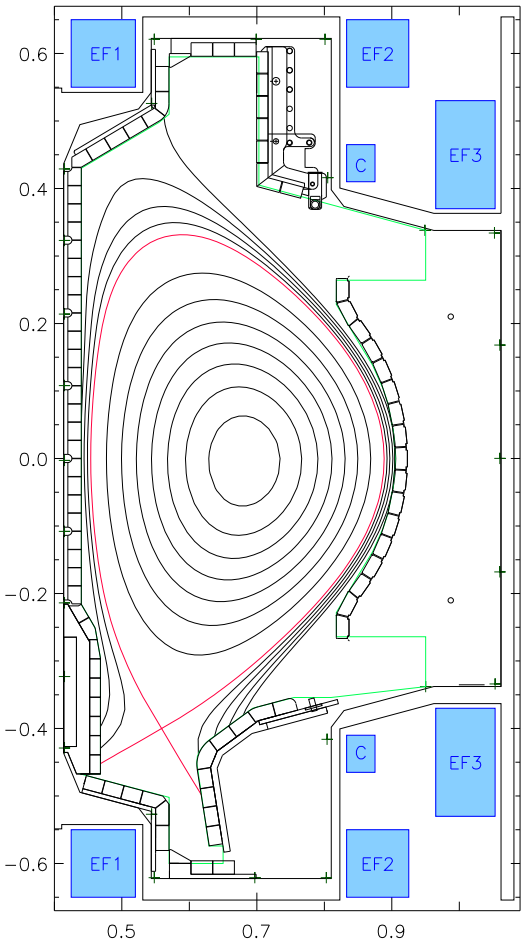
give special relevance to topical science research:

Transport: Marginal stability, pedestal, electron transp.

Edge/Divertor: SOL transport, Neutrals, Power handling.

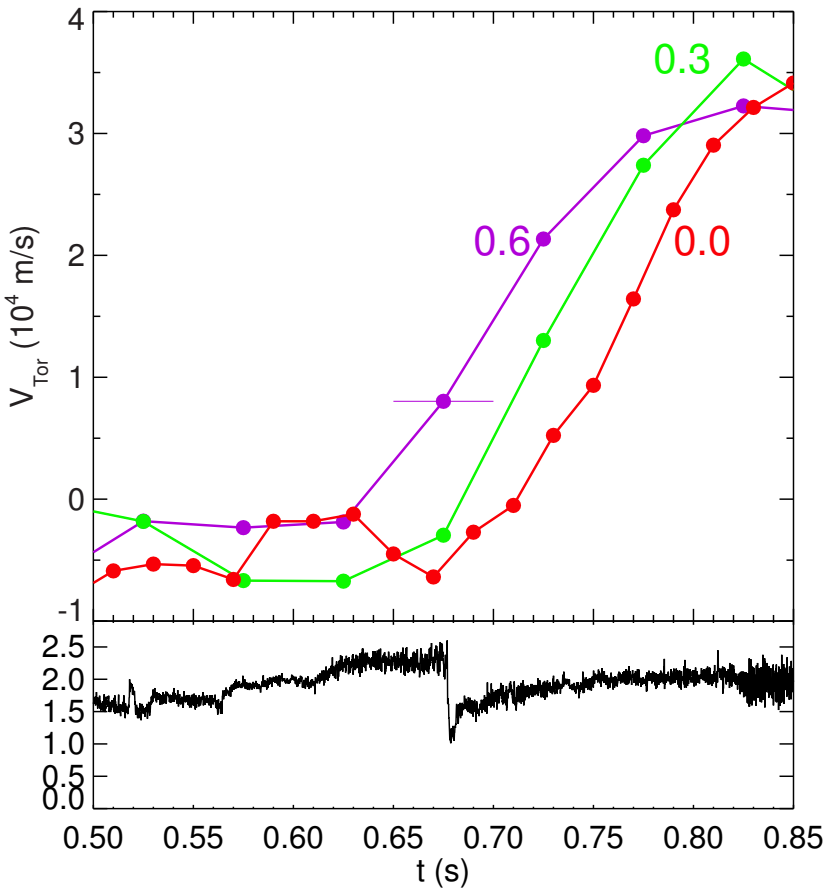
Wave/Particle: Purely RF driven. ICRF, LH physics.

MHD: Active MHD spectroscopy. ICRF/LH stabilization.



Momentum Transport Without Sources

Alcator C-Mod



C-Mod has no beam momentum source

~like burning plasma/ reactor.

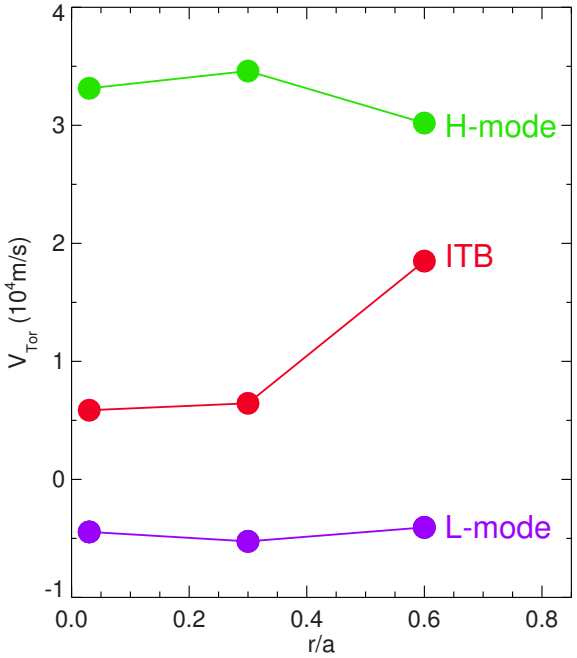
Observes rapid rotation even so.

Velocity (shear) crucial ingredient in transport.

Key to both transport science and performance.

We will continue to improve diagnostics.

And explore the subtle physics.



Velocity profile information shows momentum diffusing inwards from the edge at L-H transition.

ITB plasmas have hollow rotation profile.

Just one of many crucial Transport science objectives.

Flow and Current Control with ICRF

Take advantage of RF-driven character of C-Mod.

RF drive for active **control of flow: Mode Conversion Flow Drive?**

Is it really feasible? C-Mod gives excellent opportunity to find out.

We are proposing this as one of our Plain English goals.

Mode Conversion Current Drive

Hampered till now by

- 4-strap antenna problems
- run time limitations

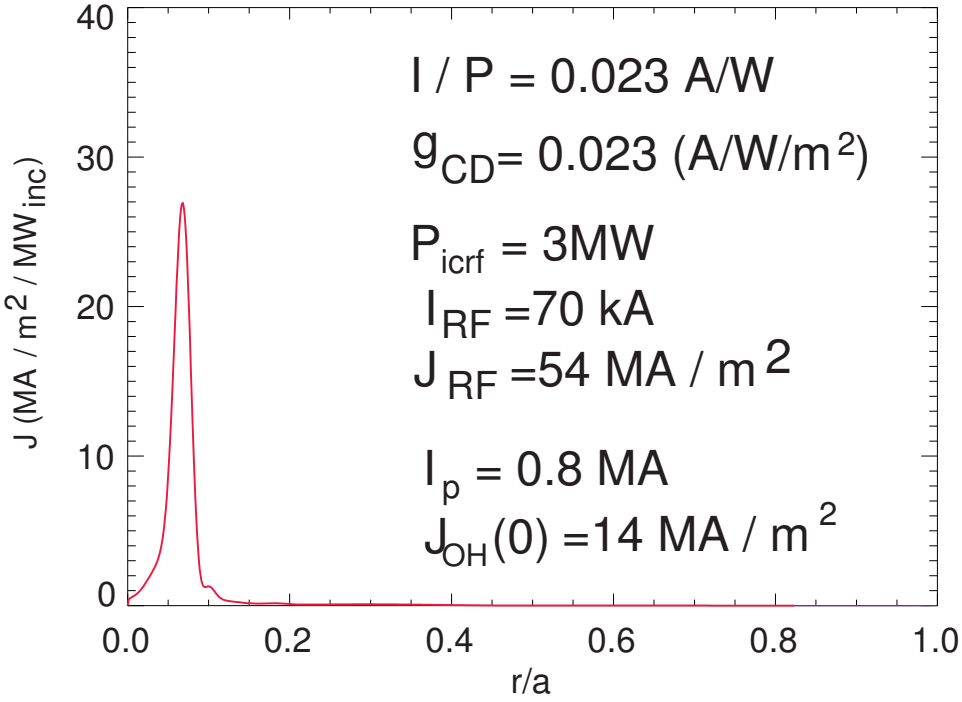
Requires asymmetric phasing.

Current density predicted

well exceeds background.

Localization may allow NTM control.

Fast-Wave CD also interesting.

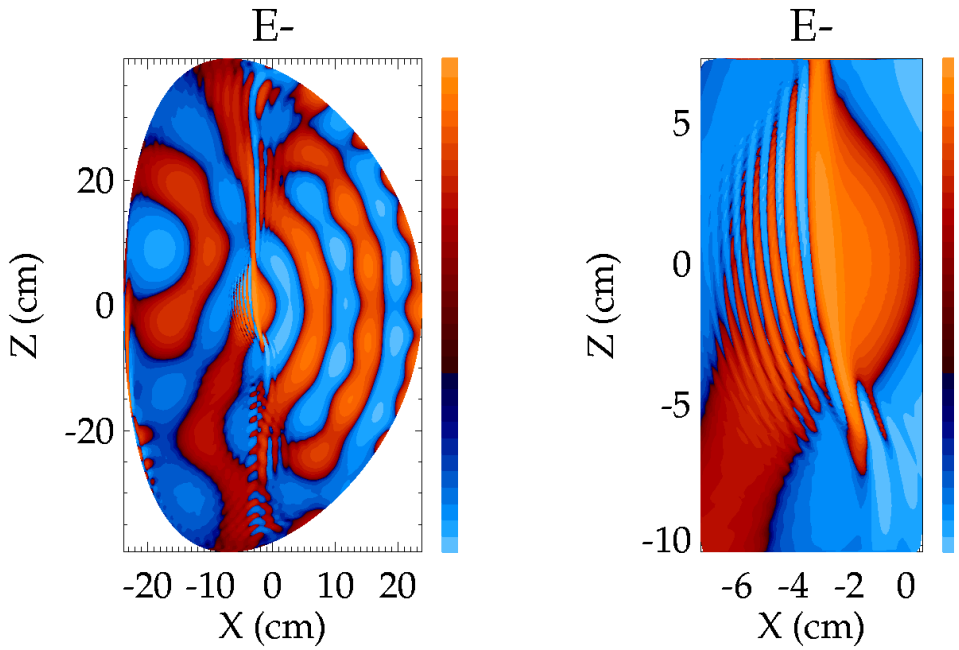


ICRF Physics and Technology

Alcator C-Mod

ICRF Physics

There is fascinating and important physics in RF, e.g. mode conversion (to ICW).



Partnership with Computer modeling.

Innovative diagnostics of waves.

RF Technology

We need to turn this from an art into a science if it is to be reliable for a Burning Plasma Experiment.

The tokamak environment is unique in having high B, copious radiation and ionization sources, disruptive eddy forces. Experiments have to be done in situ.

Studies of science of voltage limits and antenna-plasma interactions.

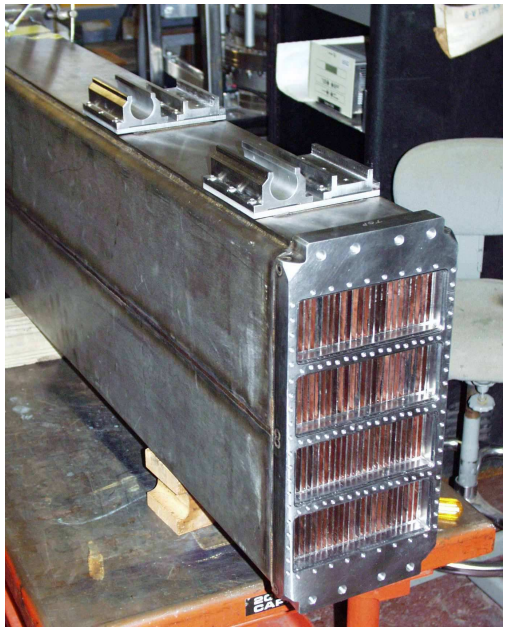
Major initiative in load-tolerant matching circuits.

Want on-site technologist participation.

Lower Hybrid Upgrade Phase I

Construction completion this month. First Plasma Ops Fall 2003.

Alcator C-Mod



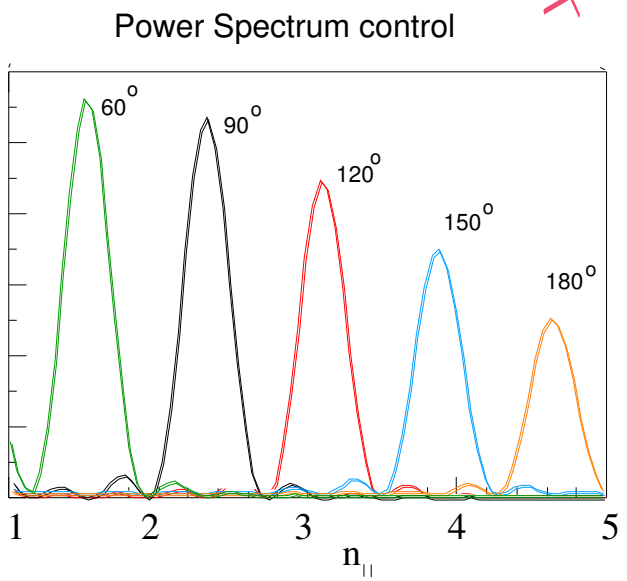
Leads to Dynamic AT Program

- Current Profile Control
- Quasi-Steady Advanced Tokamak Plasmas
- NTM suppression

Lower-Hybrid-Sustained Advanced Tokamak

Alcator C-Mod

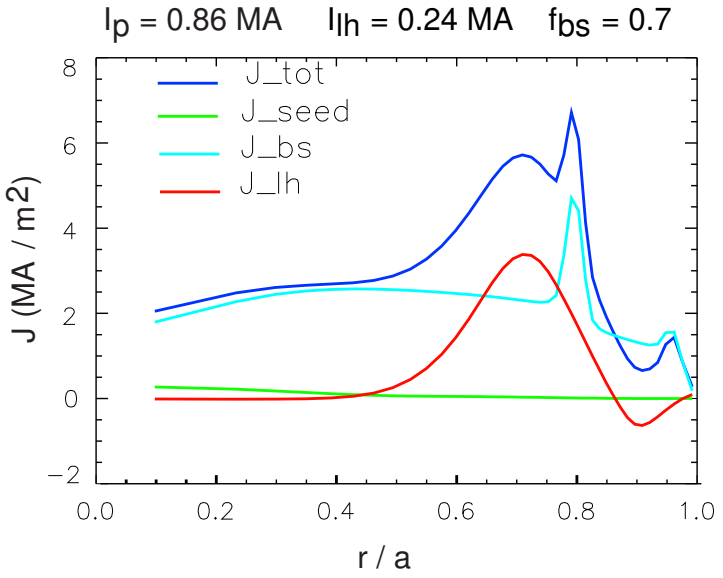
	2003 Phase I	2005 Phase II
Klystrons (250 kW each)	12	16
Source Power (MW)	3	4
4×24 waveguide grille(s)	1	2
Power density (MW/m^2)	70	45



Dynamically adjustable $n_{||}$ spectrum controls power deposition and current drive location.

Phase II: Investment in launcher yet to be made. FY2005 earliest operation.

- Total Power required for AT integrated target
- Power *density* reduced for longer pulse
- 2 launchers can have different spectra for profile tailoring.



MHD topical science

Alcator C-Mod

Non-axisymmetric control coils.

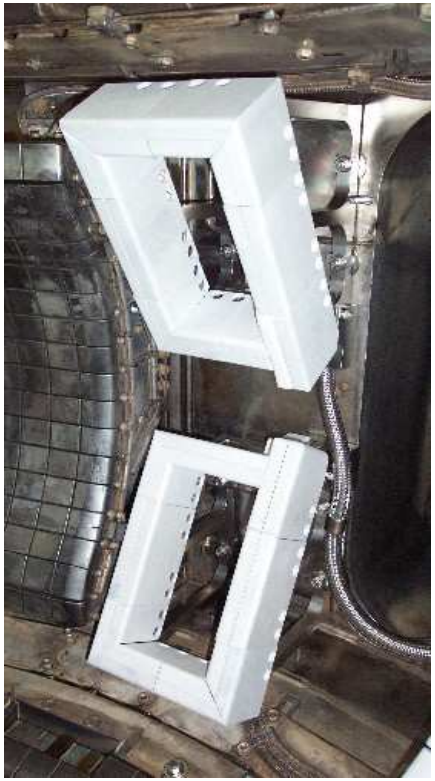
- Error Field Correction
- Locked-mode prevention
- Magnetic momentum control

Active MHD Spectroscopy

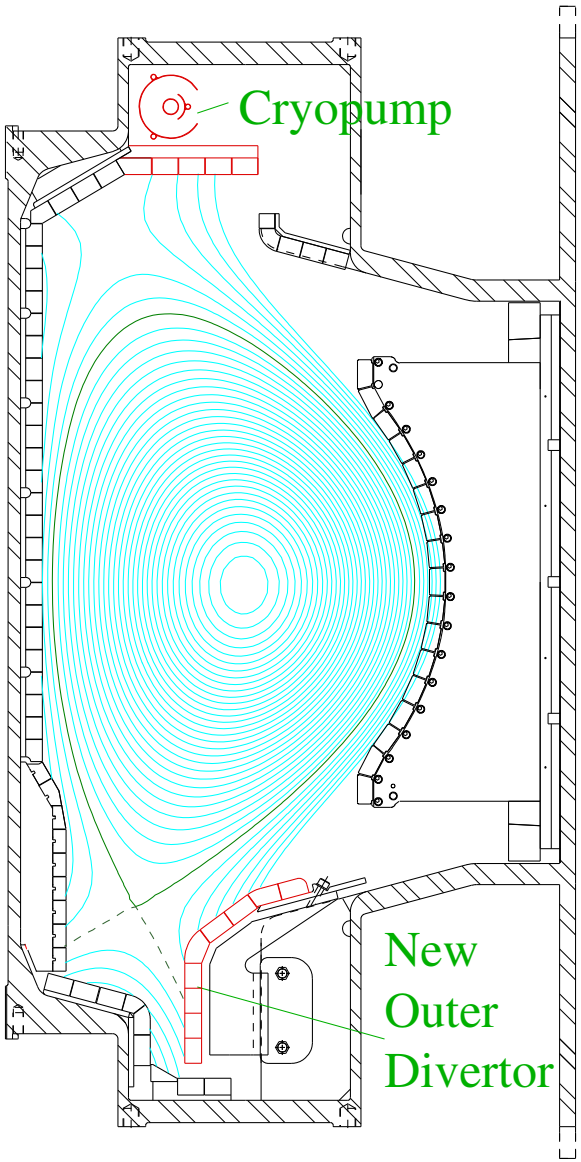
- Alfven Mode Physics
- MHD/Disruption Detection

Disruption Understanding and Mitigation

- Halo measurements
- Influence of divertor structure
- Gas jet mitigation



Divertor Upgrade Supports Density Control, Long-Pulse Heat-Flux



New upper divertor (04-05)

- accommodates the cryopump
- necessary for ∼double-null plasmas
- optimized for pumping
- neutral pressures measured

New Outer Divertor (05-06)

- Removes toroidal gaps/leading edges
- Simplified geometry, retains diagnostic access
- Tungsten-Brush Tiles. ITER technology.

C-Mod Edge/Divertor science is second to none.

Will continue groundbreaking studies on SOL transport, fluctuations, neutrals, divertor physics ...

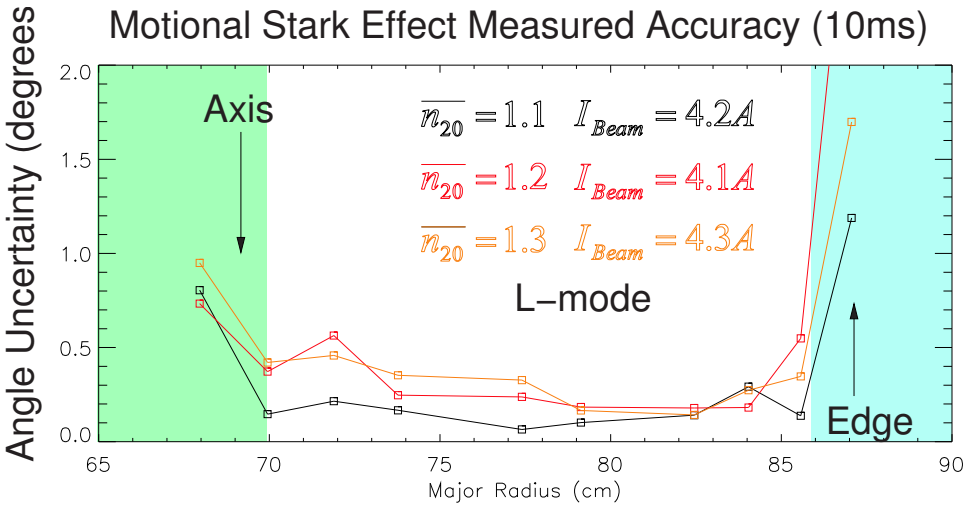
Diagnostic Upgrades Key to AT, Science

Alcator C-Mod

Diagnostic Neutral Beam

Beam loaned from U.Padova.

Gives adequate signal, measurements.

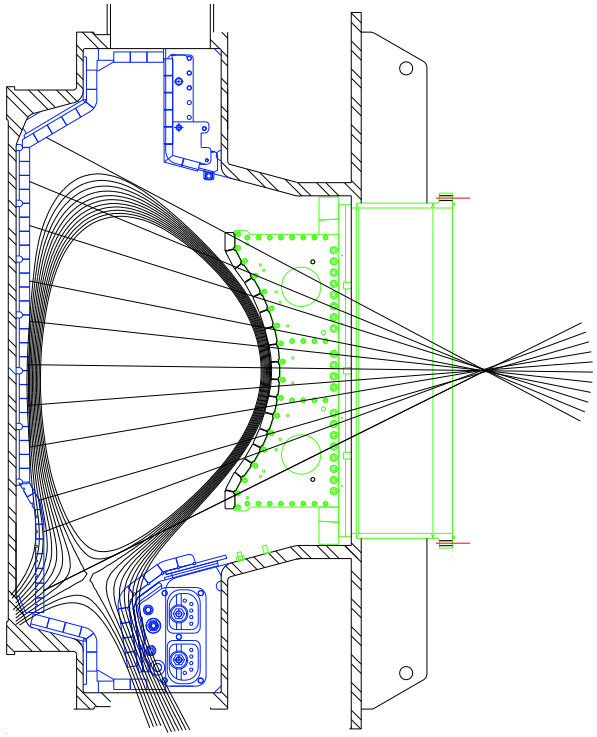


Must be returned and replaced. A higher current, long pulse beam is planned.

But no beam can penetrate to center of highest n_e Alcator plasmas.

Faraday Rotation Polarimeter

Proposed for implementation during 2005



Similar to ITER plans. Full n_e range.

Other important diagnostics for fluctuations, pedestal, wall interactions, ...

Summary by ITPA Thrust Area

Alcator C-Mod

Burning Plasmas

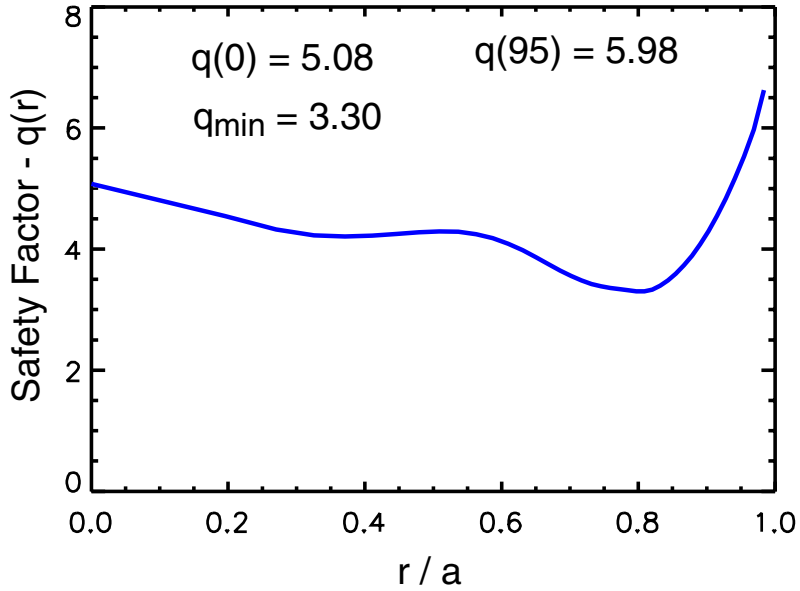
- A specific high field, high performance C-Mod thrust
- ITER-specific science in pedestals, NTM control, metal wall retention...
- ICRF physics and scaled BPX transport scenarios.

Fundamental Understanding

- Initiatives in momentum transport and control by ICRF
- LH system and Diagnostics for core transport physics
- Edge and SOL transport and control

Configuration Optimization

- Major Quasi-Steady AT thrust using LHCD



Materials and Technology

- In-situ testing of ITER W-brush technology
- ICRF science and technology especially antenna/coupling

Alcator C-Mod
Budgets, Operations & Schedule

OFES Budget Planning Meeting

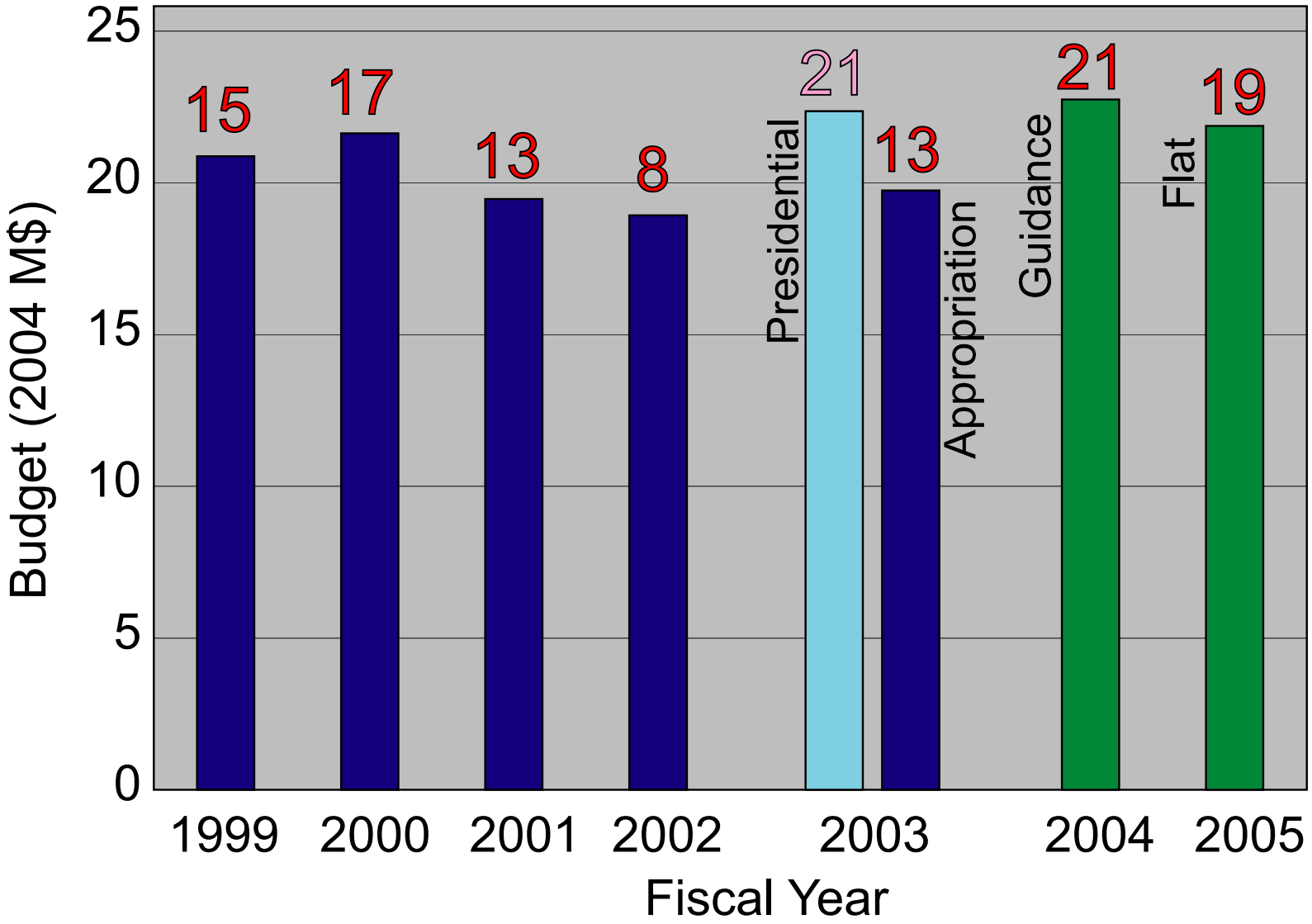
March 19, 2003

E. S. Marmar

Budget Constraints have Led to Significant Underutilization

Alcator C-Mod

C-Mod National Budgets and Research Run Weeks



FY04 Guidance Allows Significant Increase in Run Time

Alcator C-Mod

Guidance Budgets

Fiscal Year	2002	2003	2004	2005
Run Weeks	8	13	**21**	**19**
Run Hours	270	430	**700**	**630**

10% Increments in 2004 and 2005: Increase to 25 Weeks

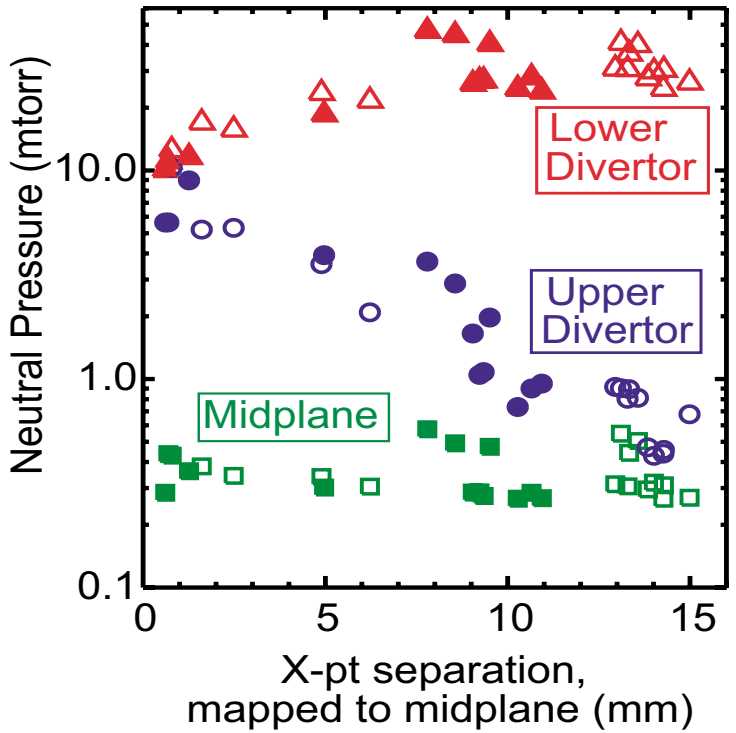
Fiscal Year	2002	2003	2004	2005
Run Weeks	8	13	**25**	**25**
Run Hours	270	430	**830**	**830**

10% Decrement in 2004 or 2005:

Fiscal Year	2002	2003	2004	2005
Run Weeks	8	13	**18**	**16**
Run Hours	270	430	**600**	**530**

Milestones Completed Since March 2002

Complete inner wall modifications	MAR 02
Measurements of rotation profile evolution	NOV 02
Measure current density profile with MSE	NOV 02
Compare single-null, double-null and inner-wall-limited discharges	NOV 02
Completion of Lower Hybrid fabrication project	APR 03



- Unbalanced Double-Null:
  - Power to lower divertor
  - Neutral density high in upper divertor (secondary separatrix)
  - Cryopump will go in upper divertor

Research Goals (FY03-FY05)

Higher performance plasmas (5 MW ICRF)	SEP 2003
Plasma flow control with radio waves (MC-ICRF)	SEP 2003
Driving electric current with radio waves (MC-ICRF)	SEP 2003
Commissioning of the microwave current drive system (LHRF)	FY 2004
Power and particle handling for Advanced Tokamak plasmas	FY 2004
Sensing approach to instability using active coils	FY 2004
Current profile control with microwaves (LHCD)	FY 2005
Sustaining plasma current without a transformer	FY 2005

C-Mod is already contributing strongly to ITER

- At least 80% of C-Mod research addressing ITER-relevant issues
- 50% of FY03 run time on experiments identified by ITPA Topical Physics Groups
- Current emphasis on
  - ITB operation with no external momentum input
  - H-Mode and Pedestal databases
  - Small/No-ELM regimes
  - High performance with strongly coupled electrons and ions
  - Dimensionless comparison experiments
  - Disruption halo-current dynamics

Contributions for ITER will expand in FY04-FY05

- Disruptions
  - Gas jet mitigation with high pressure plasma
  - All metal walls
- Current density profile control
  - NTM suppression with Lower Hybrid
  - Sawtooth control/suppression
  - Advanced Tokamak physics; steady-state scenarios
- High power handling with advanced tungsten divertor modules
- Co-deposition and hydrogen retention with all-metal walls and PFC's
- Diagnostic development, especially j(r) with high $\int n \bullet dl$

ITPA Topical Physics Group Proposals

Proposal Title	C-Mod FY03 Run Days Completed	C-Mod FY03 Additional Run Days planned
Effects of inside and vertical pellet launch		
β scaling of confinement in ELMy H-modes		1
Improving the condition of Global ELMy H-mode and Pedestal databases	3	1
Development of hybrid scenario demonstration discharges		
Development of steady-state demonstration discharges		
High performance operation with Te ~ Ti	1	2
ITB operation with no external momentum input	8	5
Improved physics understanding of QDB/QH-mode operation		
Improved understanding of β-limits with ITB operation		
Development of real-time profile control capabilities		
Dimensionally similar ITB scaling experiments		
Simulation and modelling support for T-10 turbulence studies		
Understanding of pedestal characteristics through dimensionless experiments	1	2
JET/DIII-D pedestal similarity studies		
Comparative MHD analysis and predictive modelling of type I and type II ELMy H-mode		
Stability analysis with improved edge treatment		1
Dimensionless identity experiments with JT-60U type II ELMy H-modes in DIII-D		
Impact of ELMs on the pedestal and SOL (effect of aspect ratio)		
Parameter similarity studies (L-H transition, EDA)	1	1
Parameter similarity studies Quiescent H-mode regimes)		
Scaling of type I ELM energy loss		
Tritium codeposition		1
Scaling of radial transport		1

ITPA Topical Physics Group Proposals (cont'd)

Proposal Title	C-Mod FY03 Run Days Completed	C-Mod FY03 Additional Run Days planned
Disruptions and effect on materials choices		1
Role of Lyman absorption in the divertor		
Parallel transport in the SOL		1
Pressure and size scaling of gas jet penetration for disruption mitigation		
Joint experiments on resistive wall mode physics		
Joint experiments on neoclassical tearing modes (including error field effects)		1
Neoclassical tearing mode physics - aspect ratio comparison		
Comparison of sawtooth control methods for neoclassical tearing mode suppression		
Error field sideband effects for ITER		
Preparation of ITER steady-state scenario		
Preparation of ITER hybrid scenario		
Diagnostic First Mirrors		
Measurement of q(r)	1.5	2
Confined and escaping α-particles and other fast ions		
Measurements needed to support advanced tokamak operation		
Development of radiation resistant components and ITER/reactor relevant measurement techniques		
Total FY03 C-Mod Run Days for ITPA expts	**11.5**	**16**
Total FY03 C-Mod Run Days	24	28
Fraction of run days for ITPA expts	**48%**	**57%**

Highest Priority Upgrades Included in Guidance Budgets (FY04-05)

- Replace borrowed DNB with long-pulse beam
- Cryopump (density control for AT program)
- Commissioning and operation of LHCD phase I
- Construction of phase II LHCD (additional launcher)
- Construction of new 4-strap ICRF antenna
- ICRF modifications (load tolerance, real-time matching)
- Outer divertor upgrade (higher heat load capability)
- New Diagnostics and Upgrades
  - Thomson scatt., Polarimetry, IR imaging, core and edge turbulence

Consequences of 10% Cut (FY2004)

- 3 week reduction in research operation (to 18)
- Personnel cuts:
  - 1 scientist, 1 engineer, 1.5 technicians
- Critical upgrades deferred
  - Phase II Lower Hybrid
  - Advanced 4-strap ICRF antenna
  - Outer divertor upgrade (power handling)
  - 5 year AT goal delayed nearly 1 year

Highest Priority Increments (FY04B)

- Full utilization: 4 additional weeks research operation (to 25 total)
- Increased science effort (1.5 scientists, 1 student)
- Increased engineering and technical support
- Earlier implementation of ICRF real-time matching systems (for more reliable high power operation)
- Increased spatial resolution for polarimeter (j(r) at highest densities)
- Faster replacement of obsolete CAMAC and computing resources
- Instrumentation upgrades

Consequences of 10% cut in FY05 (I) (with 10% cut in FY04 as well)

Alcator C-Mod

- 3 week reduction in research operation (to 16)
- Almost no progress on phase II Lower Hybrid
  - Earliest possible implementation of full LHCD power delayed at least to FY08
  - close to 2 year delay for 5 year AT goals
- Diagnostics deferred/delayed
  - Polarimeter delayed
  - IR cameras deferred
- Advanced tungsten divertor module tests deferred

Consequences of 10% cut in FY05 (II) (no cut in FY04)

- 3 week reduction in research operation (to 16)
- Strongly reduced pace for phase II Lower Hybrid
  - at least 6 month delay in implementation
- Bigger impact on other systems
  - Polarimeter deferred
  - IR cameras deferred
  - Tungsten divertor modules deferred
  - Real-time ICRF matching delayed
  - Outer divertor upgrade deferred
  - Vessel upgrade deferred
  - Spare ICRF FPA tube deferred (schedule risk)

Highest Priority Increments (FY05B)

- Add 6 weeks of research operation, to 25 weeks (full utilization)
- Increased science effort (2.5 scientist, 1 student)
- Increased engineering and technical support
- Complete phase II Lower Hybrid, with spare klystrons
- Complete ICRF real-time matching
- Add second view for MSE (E_r)
- Increased participation in science meetings (including ITPA)
- Complete polarimeter with increased spatial resolution
- Add Li beam polarimeter for edge/pedestal j(r)
- Faster replacement of obsolete CAMAC and computers

C-Mod National Budgets (k$, Mar 2003 Guidance)

	FY03 President	FY03 Approp	FY04A Guidance	FY04B (Incr.)	FY05A Level	FY05B (Incr.)
Research	5,790	5,123	5,889	6,340	5,804	6,739
Operations	11,972	10,483	12,496	13,986	12,586	15,287
Lower Hybrid MIE	419	124	0	0	0	0
International Collaborations	47	47	47	47	47	47
MDSplus	147	145	146	146	146	146
Lower Hybrid Upgrades	0	0	1,485	1,485	1,480	1,995
PPPL Collaborations	2,752	2,442	2,072	2,500	2,072	2,600
U. Tx. FRC Collaborations	936	425	427	540	427	560
LANL Collaborations	99	99	96	110	96	120
Alcator Project Total	**22,162**	**18,986**	**22,754**	**25,250**	**22,754**	**27,610**

Alcator C-Mod
Overview Schedule (March 2003)